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Spirometry and Flow-Volume Curves

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Instrumentation for the detection and follow-up of lung disease is frequently lacking in physicians' offices and clinics. However, equipment for diagnosis and follow-up of heart disease such as the electrocardiogram (ECG) is common in these environments. Why the difference? This difference is especially perplexing in light of the fact that some authors have said "Spirometry should be performed on most adult patients to detect chronic obstructive pulmonary disease (COPD)."[6] The following statements explain, in part, why pulmonary function testing, especially spirometry, has not come into common use:

1. The prevalence of lung disease was not known to be as widespread as heart disease. However, in recent years COPD has become a major public health problem. According to Enright and Hyatt,[6] approximately 17 per cent of men over age 40 have COPD and about 5 per cent of women have COPD, and the rate of the latter is growing rapidly.
2. The natural history of lung disease has not been as well known as that of heart disease. Recently the course of chronic airway obstruction has been studied. Spirometry is the best test for early detection of COPD. Despite the development of other pulmonary function tests that were thought to be more "sensitive" at detecting small airways disease, the ratio of the forced expired volume in the first second (FEV_1) to the forced vital capacity (FVC) is still the easiest and best test to use.[6, 34] Repeated measurements of FEV_1 allow for detection of smokers who are at high risk. Patients in this situation can "normalize" their annual decline in FEV_1 with smoking cessation.[34]
3. Early detection of COPD was not associated with an effective treatment. However, an effective therapy for COPD does exist. Smoking cessation is the most important treatment and chronic administration of bronchodilator drugs for treatment of asthma is well established.
4. For heart disease the ECG requires only that the patient lie still whereas pulmonary function testing requires good patient effort and cooperation. Standard methods are now available that make the spirometry testing simpler and more effective.
5. Equipment standards were established quickly for ECG but were slow to develop for pulmonary function testing. Even though Hutchinson[23] published the first spirometry results in 1846, more than 50 years before Einthoven[5] reported on the ECG in 1903, ECG methods were readily standardized. Instrument standards and methods for pulmonary function testing are still under development. Recently the American Thoracic Society (ATS) established recommendations for standardizing spirometry equipment and testing methods.[16]
6. Reference standards for diagnosis and determination of the severity of abnormality were quickly established for the ECG but are just now being established for spirometry.
7. Measurements and calculation of results from pulmonary function testing are quantitative tasks that most physicians and their staffs are not equipped to perform. Fortunately, today most spirometers are computerized so that the measurement and assessment of spirometry is easier.
8. Physicians have treated heart disease for many years, but only recently have environmental factors such as smoking been recognized as causing exacerbations of COPD.
9. The specialty of pulmonary disease is relatively new compared with the field of cardiology.

CHOICE OF PULMONARY FUNCTION TEST

An increasing number of pulmonary function tests are being developed and promoted to

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provide early detection of lung disease or to indicate the type and severity of such disease more accurately.[6, 34] These tests include measurement of lung volumes and flows using volume spirometers, flow meters, body plethysmography, helium dilution, and nitrogen washout. In spite of all the new developments and availability of tests, the forced spirogram is still the best test of pulmonary function.[6, 34] Spirometry is easily applied in the office or clinic and should be more widely used.

Recently there has been a flurry of activity to standardize the equipment and methods for performance of spirometry. These efforts have been spearheaded by the ATS and other international groups.[7, 12, 16, 27, 34, 35] As a result, there are now excellent recommendations for spirometry testing that should help spirometry become even a more valuable, frequently used test.[16]

SPIROMETRY: VOLUME-TIME VERSUS FLOW-VOLUME

Spirometers were first used to measure the volume of air expired from the lung. The variables measured were usually the vital capacity (VC) or the FVC that were useful only in the diagnosis of restrictive lung disease. The first clinically useful spirometer was developed by Hutchinson[23] in 1846. It took more than 100 years before the value of the timed expiratory volume curve for diagnosing airway obstruction was recognized by Gaensler.[9, 10] As a result of Gaensler's[7, 10] pioneering work the FVC maneuver was developed, which allows the measurement of the FEV_1 and other time-related measures of dynamic pulmonary function. Since that time there have been a wide variety of devices developed for spirometry. These include the water-seal, rolling-seal, and bellows-volume spirometers, along with the Fleisch and wire mesh pneumotachograph flowmeter spirometers. In 1979, after nearly 3 decades of forced expiratory spirometry use, the ATS published recommendations for spirometry performance.[12]

Because there is a slowing of the exhaled airflow with airway obstructive lung disease, motorized charts were added to the Hutchinson water seal spirometer to measure airflow. In the early 1950s, it became possible to make timed measurements of volume from a graph known as a "spirogram." The water-seal Stead-Wells spirometer was developed in the late 1950s and is still one of the best devices for measuring spirometric results.[36] By using motorized chart recordings, investigators were able to measure slopes from the volume-time curves and estimate flow. In the early 1960s, it was found that an assessment of the obstruction was more easily appreciated when expiratory flow was plotted against exhaled volume (flow-volume curve).

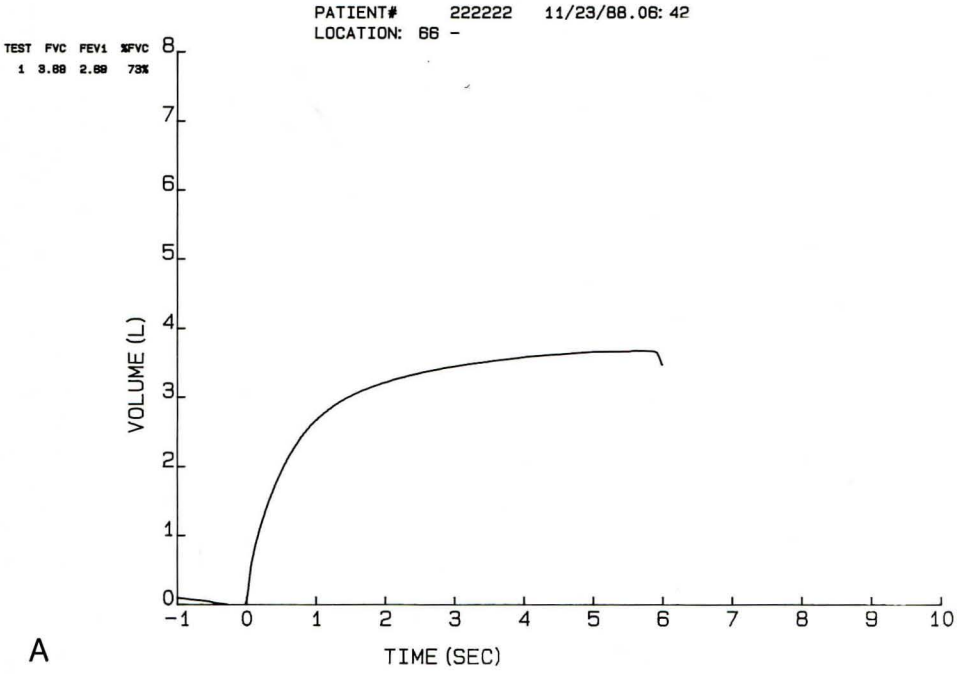
Data obtained from the forced expiratory maneuver can be used to generate both the flow-volume and volume-time curves. These curves contain the same information, but are presented in a different format for visualization purposes. Computer technology has now resolved a controversy about which approach is more useful. Since computers can quickly and easily display and plot either, both types of curves are used. Flow-volume curves "expand" the rapid exhalation segment of the forced expiratory maneuver. Flow-volume plots are very helpful in detecting inadequate patient effort. Volume-time curves present data in a more conventional format that can easily be generated by simple mechanical spirometers. Figure 1 illustrates an example of flow-volume and volume-time curves. With the computer systems associated with most spirometers today, it is convenient and appropriate to have both displays available.

SELECTING A SPIROMETER: EQUIPMENT PERFORMANCE CRITERIA

Equipment selection is pivotal to acquiring accurate spirometry results. Recommendations for spirometer performance and validation have been published by the ATS.[16] The ATS instrumentation recommendations should be followed to provide accurate spirometric data. By using accurate and validated spirometers, information from different types of spirometers, from different laboratories, and from one time period to the next can be appropriately compared.

The accuracy of a spirometer system depends on its resolution and linearity for either volume or flow depending on the type of transducer used. Because errors can occur at any step in the process of data acquisition and display, an entire spirometer system must be tested and validated. In a recent series of spirometer evaluations, computer software problems were responsible for many of the measurement errors.[30, 31]

Table 1 summarizes ATS recommendations for spirometers. Since the spirometric FVC maneuver is the most common test of pulmonary function, its performance and the corre-



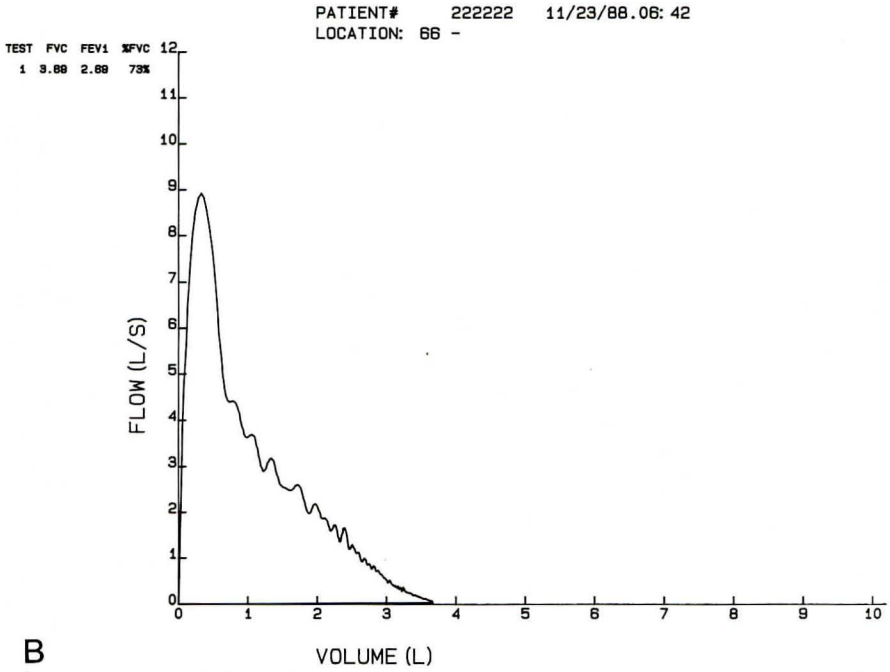


Figure 1. Volume-time (*A*) and flow-volume (*B*) spirometry curves plotted for the same patient forced expiratory maneuver.

Table 1. *Summary of American Thoracic Society Minimal Recommendations for Spirometry Systems*

TEST	RANGE/ACCURACY (BTPS)	FLOW RANGE (L/s)	TIME (s)	RESISTANCE AND BACK-PRESSURE (cmH_2O/L/s)	TEST SIGNAL
FVC	7 L ± 3% of reading, or ± 0.050 L, whichever is greater	0–12	15		24 standard waveforms
FEV_t	7 L ± 3% of reading, or ± 0.050 L, whichever is greater	0–12	t*	<1.5 from 0–12 L/s	24 standard waveforms
$FEF_{25-75\%}$	7 L ± 5% of reading, or ± 0.200 L/s, whichever is greater	0–12	15	Same as FEV_t	24 standard waveforms
$\dot{V}$	± 12 L/s ± 5% of reading, or ± 0.200 L/s, whichever is greater	0–12	15	Same as FEV_t	Manufacturer provided proof

*Time zero (t) is the time point from which all FEV_t measurements are taken. It is determined by back-extrapolation.

sponding measure of equipment performance are discussed in detail.

AMERICAN THORACIC SOCIETY RECOMMENDATIONS FOR SPIROMETRY

Forced Vital Capacity

The FVC is the maximal volume of air exhaled with maximally forced effort from a position of maximal inspiration. FVC is the VC performed with a maximally forced expiratory effort and is expressed in L (BTPS), where BTPS indicates *b*ody *t*emperature (usually 37°C), ambient *p*ressure, *s*aturated with water vapor.

Recommendation for Forced Vital Capacity Equipment. The spirometer should be capable of measuring volumes up to *at least* 7 L (BTPS) with an accuracy of *at least* ±3 per cent of the reading of ±0.050 L, whichever is greater, with flows between 0 and 12 L per second. The spirometer should be capable of accumulating volume for *at least* 15 seconds, although longer times are recommended.

Timed Forced Expiratory Volume

The timed forced expiratory volume (FEV_t) is the volume of air exhaled in the specified time during the performance of the FVC, for example, FEV_1 for the volume of air exhaled during the first second of FVC. It is expressed in L (BTPS).

Recommendation for Timed Forced Expiratory Volume Equipment. Measuring the FEV_t requires a spirometer having a volume of *at least* 7 liters. The spirometer should measure the FEV_1 within an accuracy of *at least* ±3 per cent of the reading or ±0.050 L, whichever is greater with flows between 0 and 12 L per second. The "start of test" for purposes of timing *will be* determined by the back-extrapolation method or an equivalent method. For hand measurements, the back-extrapolation method traces back from the steepest slope on the volume-time curve. The resistance to air flow from 0 to 12.0 L per second should be less than 1.5 cmH_2O per L per second.

$FEF_{25-75\%}$

The $FEF_{25-75\%}$ is the mean forced expiratory flow during the middle half of the FVC. It was formerly called the maximal mid-expiratory flow rate and is expressed in L per second (BTPS).

Recommendation for $FEF_{25-75\%}$ Equipment. The $FEF_{25-75\%}$ should be measured with an accuracy of *at least* ±5 per cent of reading or ±0.200 L per second, whichever is greater. The $FEF_{25-75\%}$ should be measured on a system that meets the recommendations for FVC equipment.

Flow

The flow ($\dot{V}$) is the instantaneous forced expiratory flow. It is expressed in L per second (BTPS).

Recommendation for Flow Measurement. Flow may be measured electronically or manually. When flow-volume loops or other flow measurements are made, at flow rates in the range of −12 to +12 L per second, the flow should be within ±5 per cent of reading or

±0.200 L per second, whichever is greater. The FVC equipment recommendations for time should be used.

Forced Expiratory Time

The forced expiratory time (FET) is the time from the back-extrapolated "time zero" until the first *in*spiratory effort following FVC, or the end of expiratory effort.

Spirometry Recorders/Displays

Paper records or graphic displays of spirometry signals are *required* for:

Diagnostic function when curves are to be used for quality control or review of the forced expiratory maneuver to determine if the maneuver was performed properly. This enables unacceptable maneuvers to be eliminated.

Validation function when curves are to be used to validate the spirometer system hardware and software for accuracy and reliability through the use of hand measurements (for example, measurement of FEV_1 using back-extrapolation by comparing computer and hand determined FEV_1s).

Hand measurement function when curves are to be hand-measured for spirometric parameters (FVC, FEV_1, and so forth) in the absence or failure of a computer.

With recent advances in computer technology, there are many different ways to display and record spirometric curves. The ATS Standardization Committee chose to broaden the initial scope of the spirometry standardization document to encourage use of computer technology.

A less stringent paper recorder requirement will suffice for *diagnostic* purposes compared with *validation* and *hand measurement* needs. If no paper recorder or printer is available or if the paper recorder does not meet the requirements for *validation* and *hand measurement* applications, then proof of validation of the accuracy and stability of the spirometer by an independent laboratory is required of the manufacturer.

Recorder Recommendations for Forced Vital Capacity Volume-Time Curves

When a volume-time curve is plotted or displayed, the minimum volume scale for each of the following conditions should be maintained:

Diagnostic function: 5 mm per L (BTPS) for volume so the graphs will be large enough to allow recognition of unacceptable maneuvers and disease patterns.

Validation and hand measurement functions: 10 mm per L (BTPS) for volume for validation and measurement functions. See the next section for the time scale of volume-time plots.

Recommendations for Forced Vital Capacity Maneuver Time Scale

The minimum time scale for each of the following conditions should be maintained:

Diagnostic function: 1 cm per second.

Validation and hand measurement functions: 2 cm per second. Larger time scales are preferred (at least 3 cm per second) when hand measurements are made, but are not required.

Recommendation for Forced Vital Capacity Flow-Volume Curves

When a flow-volume curve is plotted or displayed, exhaled flow should be plotted upward and exhaled volume plotted toward the right. A 2:1 ratio should be maintained between the flow and volume scales, for example, 2 L per second of flow and 1 L of exhaled volume should be the same distance on their respective axes. The minimum flow and volume scales should be as shown in Table 2.

EQUIPMENT VALIDATION

The diversity of FVC maneuvers encountered in clinical practice is best simulated by the use of the 24 standard waveforms.[21] These waveforms are best used to drive a computer-controlled mechanical syringe for testing integrated spirometers because these waveforms test both hardware and software.[16]

Earlier studies of spirometer accuracy have found several performance problems. Fitz-Gerald and coworkers[8] found that all seven "electronic" spirometers they tested were incapable of measuring FVC and FEV_1 accurately or reproducibly when compared with a water-seal spirometer. Testing of 12 volume-based and 7 flow-based spirometers demonstrated several problems.[17] Eight (67 per cent) of the volume-based devices performed acceptably,

Table 2. *Minimum Required Scale Factors for Time, Volume, and Flow Graphics*

	DIAGNOSTIC		VALIDATION AND MEASUREMENT	
	Resolution Required	*Scale Factor*	*Resolution Required*	*Scale Factor*
Volume (L)	0.050		0.025	
(mm/L)		5		10
Flow (L/s)	0.20		0.10	
(mm/L/s)		2.5		5
Time (ms)	20		20	
(cm/s)		1		2

whereas all seven of the flow-based devices had unacceptable performance.

With the proliferation of computerized spirometry systems, it is now important to test these systems with either a volume or flow transducer as an integrated system rather than testing only parts of the system as some authors have chosen to do. A volume or flow transducer may be inherently accurate and precise, but may be attached to a computer with an inadequate sampling rate, inadequate flow or volume resolution, inadequate calibration, or deficient computational algorithms.[16] There is a continuous flood of reports on the evaluation of spirometer performance.[20, 22, 37–39] Some are studies "funded" by spirometer manufacturers and others use "ad hoc" criteria and thus many present questionable conclusions.

We recently conducted studies to determine if 57 contemporary spirometers could meet ATS performance criteria when measuring a set of 24 standard patient spirometry waveforms.[16, 21] A computer-controlled, stepper motor–driven air pump was developed.[29] The pump was then used to evaluate 57 contemporary spirometers.[30, 31]

Results of the testing are summarized in Table 3. Only 30 (52.6 per cent) of the spirometers performed acceptably when measuring the 24 standard waveforms. Fifty-five (95 per cent) of the 58 spirometers were computerized. Software errors were found in 27 per cent of the computerized systems evaluated.

Thus, as a consequence of this testing, the purchaser and user of spirometers must take great care to be sure that they purchase and maintain their spirometers adequately in order to reduce the likelihood of erroneous test results occurring.

EQUIPMENT QUALITY CONTROL

Routine preventive maintenance, cleaning, calibration checks, verification, and quality control on equipment are important to ensure accurate spirometry results.[11, 14, 16] The spirometer's ability to measure volume accurately should be checked *at least* daily with a calibrated syringe with a volume of at least 3 L. Although there is minimal day-to-day variation in volume calibration, daily calibration checking is highly recommended so that the onset of a problem can be determined within 1 day, thereby eliminating needless reporting of false values for several weeks or months. Spirometer systems should be evaluated for leaks on a daily basis. *At least* quarterly, volume spirometers should have their calibration checked over their

Table 3. *Performance by Spirometer Type*

TYPE	TOTAL NUMBER	ACCEPTABLE NUMBER (%)	MARGINAL AND UNACCEPTABLE NUMBER (%)
Bellows	5	5 (100)	0 (0)
Water seal	7	6 (86)	1 (14)
Dry rolling seal (horizontal)	11	7 (64)	4 (36)
Ceramic pneumotachometer	4	2 (50)	2 (50)
Hans Rudolph (screen) pneumotach	5	2 (40)	3 (60)
Fleisch pneumotachometer	7	3 (43)	4 (57)
Vertical—dry rolling seal	8	3 (38)	5 (62)
Miscellaneous flowmeters	7	2 (29)	5 (71)
Turbine flowmeter	3	0 (0)	3 (100)
Total	57	30 (52.6)	27 (47.4)

entire volume range (in 1-L increments) using a calibrated 3-L syringe.

SUBJECT/PATIENT TEST PERFORMANCE

Personnel Qualifications

Interactions between technician and patient or subject is crucial to the performance of adequate spirometry since it is such an effort-dependent maneuver. Technicians must be selected and trained, and must maintain a high level of proficiency to assure optimum results. The ATS has made recommendations for laboratory personnel performing a variety of pulmonary function testing tasks[15]; they are described in detail in the article by Mahler and Loke elsewhere in this issue.

Computer Use

The use of computers to perform spirometry has accelerated in the past 5 years. Validated computerized spirometry systems will simplify and enhance the measurement and interpretation of spirometry. Because of the increased use of computers in pulmonary laboratories and the problems associated with them, the ATS has published "Computer Guidelines for Pulmonary Laboratories."[13]

Instruction and Maneuver

Subjects should be instructed in the FVC maneuver, and the appropriate technique should be *demonstrated.* A *minimum* of three acceptable FVC maneuvers should be performed. If a subject has large variability between expiratory maneuvers, reproducibility criteria may require that up to eight acceptable maneuvers be performed.

End of Test

Subjects should be verbally exhorted to continue squeezing out the air at the end of the FVC maneuver. "End of Test" will occur when there is:

1. An obvious plateau in the volume-time curve resulting in no change in volume for *at least* 2 seconds (a volume decrease is, for the purposes of end-of-test selection, equivalent to no change in volume) with an exhalation time of *at least* 6 seconds (longer times are frequently needed for subjects with airway obstruction). For the purposes of this criterion, no change in volume is the minimal detectable volume of the spirometer. Minimum detectable volume *must be* at least 0.040 L; or
2. A forced exhalation of reasonable duration. (For example, exhalation times of greater than 15 seconds in subjects with severe airway obstruction will rarely change clinical decisions and longer exhalations are seldom justified); or
3. When, for legitimate clinical reasons, the subject cannot or should not continue further exhalation.

Although the end-of-test criteria defined previously are reasonable and adequate in most situations, spirometers should not prevent the continued accumulation of volume after the end of test criteria are met.

Minimum Forced Vital Capacity Exhale Time

A minimum exhalation time of 6 seconds, unless there is an obvious plateau, is required to obtain maximal FVC results. Longer times are often required to achieve "end of test," particularly in individuals with airway obstruction.

Satisfactory Start of Test

To achieve accurate "time zero" and ensure that the FEV_1 comes from a maximal effort curve, the extrapolated volume should be less than 5 per cent of the FVC or 0.100 L, whichever is greater.

Maximum Number of Maneuvers

Although there may be some circumstances in which more than eight consecutive FVC maneuvers are needed, eight maneuvers are considered a practical upper limit for most subjects.

Environmental Conditions

Spirometric testing with ambient temperatures of less than 17°C or above 40°C is not recommended. Ambient temperature should *always* be recorded and reported to an accuracy of ±1°C. Spirometer users should be aware of

the problems associated with testing performed at lower temperatures.

Nose Clips

Use of nose clips is encouraged but not required.

TEST SELECTION AND REPORTING OF RESULTS

The largest FVC and the largest FEV_1 (BTPS) should be recorded, after one examines the data from all of the acceptable curves, *even if the two values do not come from the same curve.* Other measures such as the $FEF_{25-75\%}$ and/or the $\dot{V}$ should be obtained from the single "best-test" curve. The "best-test" curve is defined as the test that meets the acceptability criteria and gives the largest sum of FVC plus FEV_1.[16]

FVC Maneuver Acceptability

Acceptability will be determined by ascertaining that the previously outlined recommendations above are followed. In addition the technician should make certain that the subject understood the instructions and performed the maneuver with a maximum inspiration, with a good start, with a smooth continuous exhalation, with maximal effort, and without the following:

1. An unsatisfactory start of expiration, characterized by excessive hesitation or false start, or extrapolated volume of greater than 5 per cent of FVC or 0.100 L, whichever is greater.
2. Coughing during the first second of the maneuver, thereby affecting the measured FEV_1 value, or any other cough, which, in the technician's judgment, interferes with measurement of accurate results.
3. Valsalva maneuver (glottis closure).
4. Early termination of expiration. (In a *normal* subject this would be before completion of the breath—*usually less than a 6-second maneuver.* In an obstructed subject a longer time is required.)
5. A leak.
6. An obstructed mouth piece, e.g. obstruction due to the tongue being placed in front of the mouthpiece, false teeth falling in front of the mouthpiece, and so forth.

Determining Reproducibility of Results

As a goal during test result performance, the largest FVC and second largest FVC from acceptable curves should not vary by more than 5 per cent of the reading (expressed as a percentage of the largest observed FVC regardless of the curve on which it occurred) or 0.100 L, whichever is greater. In addition to the FVC criteria, the largest FEV_1 and the second largest FEV_1 (expressed as a percentage of the largest observed FEV_1 regardless of the curve on which it occurred) should not vary by more than 5 per cent of the reading or 0.100 L, whichever is greater.

The reproducibility criteria are used as a guide to whether more than three FVC maneuvers are needed; these criteria are *not* to be used for excluding results from reports or for excluding subjects from a study. Unacceptable maneuvers should be discarded before applying the reproducibility criteria.

The only criterion for unacceptable subject performance, requiring elimination from further consideration, is the generation of fewer than two acceptable curves. No spirogram should be rejected solely on the basis of its poor reproducibility, provided three acceptable maneuvers were obtained. Reproducibility of results should be considered at the time of interpretation. Use of data from maneuvers with poor reproducibility is left to the discretion of the interpreter.

SELECTING REFERENCE VALUES

Most laboratory tests of organ function are measured and "normalized" to a function of body size; for example, hemoglobin is usually reported in relation to mL of blood rather than total blood volume.[1] Spirometry values are usually reported in absolute units of L. Traditionally the major determinants of "normality" have been made by comparing the results obtained with those found in a healthy person of the same age, sex, and size.[1, 3, 19, 22, 24–26] Expected or reference values are derived from prediction equations describing the relationship of lung function to sex, age, and height at the minimum. This area of spirometry standardization is at an early stage in its development. The ATS held a workshop with international participants to address "Lung Function Testing: Selecting Reference Values and Interpretative Strategies" in September 1988. The final conclusion and recommendations from this workshop are not yet available. However, some of the concepts and concerns discussed at the conference will be of value to those performing spirometry.

The prediction equations selected must be

appropriate to the patients or subjects under study. Some prediction equations have been based on studies of unique religious and ethnic groups, which may not be representative of white Europeans or Americans as a whole.[24] For example, from studies of black populations the various measurements of lung functions appear to be 13.2 per cent larger for a given height in whites when compared with blacks.[33] Thus, the use of this scaling factor offers a reasonable approximation to adapt white predicted values to blacks.

Recent evidence has shown that socioeconomic status has a major effect on pulmonary function.[24] For example, following a change to western diet and attitudes, the body and lung sizes of Chinese and Japanese individuals have increased to values similar to those of whites.

All currently available prediction equations are based on cross-sectional data. Consequently, they should not be used to predict longitudinal changes. Indeed, the prediction equations of today will inevitably become obsolete, and frequent (perhaps every 10 years) revisions will be necessary.

The Intermountain Thoracic Society has recently published its manual of uniform laboratory procedures.[28] This manual contains tables for reference values as well as interpretive strategies in both table and computer programs.[4, 28] The California Thoracic Society has published a similar book that emphasized the controversy associated with selecting reference values and interpretation methodology.[2] Additional texts dealing with these issues are available as well.[3, 26]

INTERPRETATION OF RESULTS

In terms of the use of spirometry test results, the definition of "normal" is usually intended to provide a range of reference values to which one can compare measured values and associate them with risk factors of disease categorization.[25] Three general methods are used for establishing the lower limits of "normal":

1. The predicted value ± a "magic value" as a percentage of predicted (for example, the "magic value" of less than 20 per cent of predicted, which is used for many lung function tests, or an FEV_1/FVC ratio of less than 70 per cent).
2. The 95th percentile method: Measured values are expressed as a percentage of predicted. The lower limit of normal is defined as the value above which 95 per cent of a normal population lies.
3. The 95 per cent confidence interval (CI) method: The lower limit of normal is defined as the predicted value minus the 95 per cent CI. The 95 per cent CI is close to 1.96 × the standard error of the estimate (SEE) for a two-tailed test and 1.65 × SEE for a one-tailed test.

Method 1 has little scientific or statistical validity and has very little to recommend it except for tradition and convenience. Method 2 has the best scientific and statistical foundation,[25] but for the moment suffers from the lack of sufficient data from published reference studies to be easily applied.[28] Thus, for the moment Method 3 using the CI method seems most appropriate. Details involving the application of the method are found in the Intermountain Thoracic Society's "Orange Manual."[28]

The classification of spirometry into normal and abnormal groupings and into disease categories such as mild, moderate, and severe airway obstruction is easily accomplished once criteria have been established.[28] The meaning of such classifications requires clinical information. For example, the meaning of an FVC measurement that is just below the lower limit of normal is different in a young, healthy, nonsmoking individual than it is in a person who presents for evaluation of dyspnea or who has an abnormal chest radiograph. In the first case, the probability of a false-positive test is large since the prior probability of disease is very low. In the second case, the probability of a true-positive test is high because the symptoms and/or the abnormal radiograph increases the prior probability of disease.

CONCLUSION

Spirometry is currently being used to make decisions about individual patients such as: Does this subject have enough evidence of impaired lung function to preclude working at a specific job? Should corticosteroid treatment be continued? Does the person qualify for full disability compensation on the basis of impaired lung function? Should the subject's insurance status be changed? Answers to each of these questions can be based on results from the forced expiratory spirometric maneuvers and can have a dramatic effect on a person's lifestyle, standard of living, and future treatment. Therefore, it is incumbent on those who perform spirometric testing to be certain that the equipment meets ATS recommendations and that the techniques that elicit best patient effort are applied. Methods and suggestions have been

presented in this article that should assist in these important tasks.

REFERENCES

1. Becklake MR: Concepts of normality applied to the measurement of lung function. Am J Med 80:1158–1163, 1986
2. Clausen JL, Zarins LP (eds): Pulmonary Function Testing—Guidelines and Controversies. New York, Academic Press, 1982
3. Cotes JE: Lung function: Assessment and Application in Medicine, ed 4. Oxford, Blackwell Scientific Publications, 1979, pp 1–604
4. Crapo RO, Morris AH, Gardner RM: Reference spirometric values using techniques and equipment that meet ATS recommendations. Am Rev Respir Dis 123:659–664, 1981
5. Einthoven W: Win neues Galvanometer. Ann Physik 12(suppl)4:1059–1071, 1903
6. Enright PL, Hyatt RE: Office Spirometry. Philadelphia, Lea & Febiger, 1987
7. Ferris BG Jr (principal investigator): Epidemiology standardization project. Am Rev Respir Dis 37:185–191, 1978
8. FitzGerald MX, Smith AA, Gaensler EA: Evaluation of "electronic" spirometers. N Engl J Med 289:1283–1286, 1973
9. Gaensler EA: Analysis of ventilatory defect by timed capacity measurements. Am Rev Tuberc 64:256–278, 1951
10. Gaensler EA: An instrument for dynamic vital capacity measurement. Science 114:444–446, 1951
11. Gardner RM: Calibration and quality control in the pulmonary laboratory—why? Respir Care 28:745–747, 1983
12. Gardner RM (chairman): ATS statement—Snowbird workshop on standardization of spirometry. Am Rev Respir Dis 119:831–838, 1979
13. Gardner RM, Clausen JL, Cotton DJ, et al: Computer guidelines for pulmonary laboratories. Am Rev Respir Dis 134:628–629, 1986
14. Gardner RM, Clausen JL, Crapo RO, et al: Quality assurance in pulmonary function laboratories. Am Rev Respir Dis 134:626–627, 1986
15. Gardner RM, Clausen JL, Epler G, et al: Pulmonary function laboratory personnel qualifications. Am Rev Respir Dis 134:623–624, 1986
16. Gardner RM, Hankinson JL, Clausen JL, et al: ATS statement on standardization of spirometry—1987 uptake. Am Rev Respir Dis 136:1285–1298, 1987
17. Gardner RM, Hankinson JL, West BJ: Evaluating commercially available spirometers. Am Rev Respir Dis 121:73–82, 1980
18. George RB, et al: ATS respiratory care committee position paper: Director of pulmonary function laboratory. ATS News 4:6, 1978
19. Glindmeyer HW: Predictable confusion. J Occup Med 23:845–849, 1981
20. Gunawardena KA, Houston K, Smith AP: Evaluation of the turbine pocket spirometer. Thorax 42:689–693, 1987
21. Hankinson JL, Gardner RM: Standard waveforms for spirometric testing. Am Rev Respir Dis 126:362–364, 1982
22. Hess D, Chieppor PJ, Johnson K: An evaluation of the Respiradyne II spirometer. Respiratory Care 32:1123–1130, 1987
23. Hutchinson J: On the capacity of the lungs and on the respiratory functions with the view of establishing a precise and easy method of detecting disease by the spirometer. Trans Med Chir Soc Lond 29:137–252, 1846
24. Knudson RJ, Lebowitz MD, Holberg CJ, Burrows B: Changes in the normal maximal expiratory flow-volume curve with growth and aging. Am Rev Respir Dis 127:725–734, 1983
25. Lebowitz MD, et al: Epidemiological importance of significant change in health status. Eur J Epidemiol 3:390–398, 1987
26. Miller A (ed): Pulmonary function tests; A guide for student and house officer. Orlando, FL, Grune & Stratton, 1985, pp 1–275
27. Morgan WKC (chairman): Committee recommendations: The assessment of ventilatory capacity: Statement of the committees on environmental health and respiratory physiology. Chest 67:95–97, 1975
28. Morris AH, Kanner RE, Crapo RO, Gardner RM: Clinical Pulmonary Function Testing: A Manual of Uniform Laboratory Procedures, ed 2. Salt Lake City, Intermountain Thoracic Society, 1984
29. Nelson SB, Gardner RM: Computer-controlled spirometry waveform simulator. Respiratory Care 31:964, 1986
30. Nelson SB: Commercially available spirometers: A performance evaluation. MS Thesis, University of Utah, Salt Lake City, 1987
31. Nelson SB, Gardner RM, Crapo RO, et al: Performance evaluation of contemporary spirometers. Am Rev Respir Dis, in press
32. Quanjer PH, et al: Standardization of lung function testing. Report of working party of European community for coal and steel. Bull Eur Physiopathol Respir 19(suppl 5), 1983
33. Rossiter CE, Weill H: Ethnic differences in lung function: Evidence for proportional differences. Intl J Epidemiol 3:56–61, 1974
34. Stanescu DC, Rodenstein DO, Hoven C, et al: "Sensitive tests" are poor predictors of the decline in forced expiratory volume in one second in middle-aged smokers. Am Rev Respir Dis 135:585–590, 1987
35. Taussig LM, et al: Standardization of lung function testing in children. J Ped 97:668–678, 1980
36. Wells H, Stead WW, Rossing TD, et al: Accuracy of an improved spirometer for recording fast breathing. J Appl Physiol 14:451–454, 1959
37. Wever AMJ, Britton MG, Hughes DTD, et al: Clinical evaluation of five spirometers. Eur J Respir Dis 62:127–137, 1981
38. Yeh MP, Adams TD, Gardner RM, et al: Rotameter flowmeter: Its implications to exercise testing. J Appl Physiol 63:1289–1295, 1987
39. Zimnicki GL, Kline JL, MacDonell RJ: Evaluation of the Respiradyne pulmonary function monitor. Respiratory Care 32:261–267, 1987

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